ASSESSMENT OF CONTAINMENT OPTIONS FOR MODULAR-HTGRs

Each of the four alternative technology-neutral containment functional performance criteria (i.e., options) are discussed and evaluated on the basis of its specific application to modular HTGRs. In support of and in advance of these evaluations, the following additional modular HTGR-specific information is provided.

Modular HTGR Approach to Radionuclide "Containment"

Compared to operating LWRs, modular HTGR designers have proposed a very different design approach to prevent unacceptable releases of radionuclides to the environs. Modular HTGRs are designed to contain the vast majority of radionuclides at the source, within billions of small, high integrity, refractory coated fuel particles. To ensure dose acceptance criteria are met, the failure of a radiologically significant fraction of the fuel particles is not permitted during either normal operation, anticipated transients, design basis accidents or beyond design basis accidents. Thus, the safety philosophy of modular HTGRs is to assure the integrity of the coated particle fuel particle (i.e., the "containment barrier"). Modular HTGR designers propose to use high quality fuel, which has been qualified for the specified operating and accident conditions and then reliably limiting the fuel operating and accident conditions (e.g., maximum transient fuel temperature) to values within the qualification envelope. This objective is to be reliably accomplished with a reactor design having a relatively low core power density compared to operating LWRs (to limit accident decay heat input into the core) and inherent safety characteristics and simplified passive means, to shutdown and remove core decay heat in the event of an transient or accident. The safety philosophy is to assure the fuel containment barrier rather than to allow significant fuel failures and then have to rely extensively on either backup barriers (such as a containment) or other mechanistic barriers associated with the core graphite structures or reactor coolant pressure boundary. In this regard, preventing significant releases of fission products from the fuel is consistent with the ultimate objective of the Commission's advanced reactor policy which expects advanced reactor designs to minimize the potential for severe accidents.

Mechanistic Barriers

As allowed by Commission policy, in determining on-site and offsite dose, modular HTGR designers propose to take credit for all of the multiple "mechanistic barriers" to radionuclide transport associated with the fuel, core graphite structures, reactor coolant pressure boundary and containment. For modular HTGRs, designers propose that the containment be relied on to assist in protecting the fuel, core graphite, the reactor pressure boundary and in meeting dose criteria, but need not provide an essentially leak-tight barrier against the release of radionuclides to the environs. Modular HTGR designers have stated that given the effectiveness of the other mechanistic barriers, the containment provides only additional safety margin and margin to the dose criteria. However, it's contribution as a mechanistic barrier is not required to meet the radionuclide dose criteria, at least for the events that modular HTGR designers have selected for the event categories.

Vented Low Pressure Containment

Modular HTGR reactor coolant system (RCS) circulating activity and plateout activity are to be monitored and controlled in order to limit radionuclides within the RCS to relatively low levels during normal operation. For this reason, modular HTGR designers have proposed that the containment be what is referred to as a vented low pressure containment (VLPC). For moderate-to-large pipes breaks in the RCPB, a VLPC is designed to allow the hot pressurized helium and the limited contained and entrained radioactivity in the reactor coolant system to blowdown directly to the environs. During the blowdown, credit is usually taken for plateout of some of the condensible radionuclides on the cooler surfaces of the VLPC. Accordingly, radionuclides released to the environs during the RCS blowdown (i.e., the prompt radionuclide release) is expected to involve a relatively low radiological dose, even at the site boundary. Additionally, modular HTGR designers state that depressurizing the RCPB and VLPC down to atmospheric pressure through a reclosable ventilation duct removes the motive force, that might otherwise be available for radionuclide transport later in the accident, when additional fractional failure of fuel particles are expected to occur (i.e., delayed radionuclide release).

The Effect of Event Selection on Containment Functional Performance and Design

Modular HTGR design and safety analysis information reveals that the functional performance and the design of the VLPC depends on the RCPB break scenarios included in the design-basis. This is due to the potential for additional challenges to the core and increase in the delayed accident source term that can be caused by significant air ingress from a RCPB break. These additional challenges include the potential for degradation of the graphite core support structures due to oxidation (i.e., degradation of core cooling), the potential for additional fuel particle failures due to oxidation of the ceramic coatings and the potential for re-introducing a motive force to radionuclide transport from the core, the RCS and the VLPC with the onset of natural circulation gas mixture flow through the core. A severe air ingress event therefore has the potential to significantly degrade the mechanistic barriers, significantly increase the magnitude of the delayed source term and potentially significantly increase the dose consequences.

HTGR designers state that the VLPC has a functional role to prevent a large volume air ingress in order to prevent these consequences. Thus, a severe air ingress event can establish a maximum allowed (post-blow down) leakage rate for the VLPC. For example, failure of the large diameter cross-connect duct/vessel, or failure of smaller diameter vessel penetrations above and below the core can result in severe air ingress events. However, recent HTGR design and safety analysis information indicates that the more challenging RCPB breaks are not always selected for analyzing air ingress consequences since they are considered to be very low probability events. Less severe air ingress events may not be sufficiently challenging to require establishment of a specific VLPC leakage rate. Additionally, some modular HTGR designers have targeted break prevention and/or alternative mitigation strategies (that would seek to take advantage of the relatively long time available for human actions due to the expected very slow rate of core heat up) to address potential severe air ingress events as an alternative to reducing the allowed post-blowdown VLPC leakage acceptance criteria.

Evaluation of Technology-Neutral Containment Options for Modular HTGRs

The staff has evaluated each of the above four options for modular HTGRs based on the above metrics. These modular HTGR-specific assessments supplement (rather than replace) the technology-neutral assessments provided in Attachment 2.

Option 1: The containment must adequately reduce radionuclide releases to the environs to meet the onsite and offsite radionuclide dose acceptance criteria for the events selected for the event categories.

For advanced HTGRs this option would likely allow a VLPC, currently proposed by the HTGR designers. As acknowledged by HTGR designers, it would require a high of level assurance that fuel and other SSC performance and related uncertainties are well-understood for a wide range of conditions and that the fuel fabrication process maintains the requisite fuel quality over the life of the plant. Also, HTGR designers state that a function of the VLPC is to limit air ingress into the core to prevent excessive graphite oxidation and fuel degradation but some propose a large allowable VLPC leakage rate (e.g., 100%/day) and/or other mitigation approaches to limit the volume of air that might otherwise enter the core. Not all HTGR designers propose to include in the VLPC design-basis, the more severe air ingress events since they consider them to be very low probability events. This option would not explicitly require inclusion of these more severe air ingress events although the staff could recommend that they be included and enhancements applied, if needed, based on deterministic engineering judgement. However, if included, such enhancements could include strengthened prevention measures or alternative mitigation strategies. Accordingly, this option could result in allowing a VLPC with a relatively large allowed leakage rate.

It is not explicitly responsive to the July 30, 1993 SRM for SECY-93-092 which directed the staff to address in the development of the containment performance criteria, loss of primary coolant pressure boundary integrity events which can result in ingress of air leading to natural circulation through the core with the potential loss of fuel particle integrity. However, as noted above such breaks could still be included in the design-basis if deterministic engineering judgement found that they should be included in order to bound uncertainties.

Except for any additional required enhancements, this option would not involve incremental costs, which HTGR designers believe could make such designs less competitive.

Because modular HTGRs, are expected to involve a much lower release of radionuclides into the containment during normal operation and frequency-based design-basis events, public confidence could be enhanced. However, because this option would likely allow an HTGR containment with less capability to reduce radionuclide releases to the environs compared to LWR containment designs, it might be perceived as providing less protection, thereby potentially reducing public confidence overall.

Option 2: The containment must adequately reduce radionuclide releases to the environs to meet the onsite and offsite radionuclide dose acceptance criteria for the events selected for the event categories (including within the design-basis category, selected credible events having the potential for high consequence source terms).

This criterion is the same as Option 1 except that it specifically requires that credible very low probability, high consequence, source term events, such as, potentially, the failure of the cross-connect duct/vessel, be included in the design-basis event category. Such bounding source term events would be used to assess whether all mechanistic barriers, including the containment performance, provide sufficient defense-in-depth in reducing radionuclide transport, to meet dose criteria. For modular HTGRs, this option would likely allow a VLPC, but for some HTGR designs, it could necessitate limiting the volume of air (i.e., lower VLPC leakage rate) that would be available for core oxidation and delayed radiological source term release to the environs. HTGR designers may seek to pursue alternative mitigation strategies to limit the volume of air ingress into the core rather than limiting the post-blowdown leakage rate of the VLPC, which the staff may, or may not accept as sufficiently reliable. If alternative strategies are not accepted, limiting the VLPC post-blowdown leakage rate would likely be required. This option is explicitly responsive to the July 30, 1993 SRM for SECY-93-092. The SRM directed that modular HTGR containment performance criteria include consideration of a loss of primary coolant pressure boundary integrity which results in ingress of air leading to natural circulation through the core and the potential loss of fuel particle integrity.

Currently, most (but not all) worldwide modular HTGR designers do not include in the design-basis event category, such bounding events of potentially very low probability. For designs that currently do not include such events, additional technology development would be required to support the source term calculation associated with air ingress and graphite and fuel oxidation. Additionally, for modular HTGR designs that currently do not include a cross-connect duct/vessel failure in the design-basis envelope, if included, the significantly higher thermal-dynamic loads on the VLPC structures could require structural changes to the VLPC in order for the higher stresses to meet structural stress (i.e., American Society for Mechanical Engineers, ASME) limits. This would add to the design and construction costs of the VLPC for these plants.

Because modular HTGRs, are expected to involve a relatively low release of radionuclides into the VLPC during normal operation and frequency-based design-basis events, public confidence could be enhanced. If more challenging and lower probability events were included in the design-basis category and air ingress and delayed source term were limited by the limiting the VLPC leakage rate, it would likely further increase public confidence relative to Option 1.

Option 3: The containment must adequately reduce radionuclide release to the environs to meet the onsite and offsite radionuclide dose acceptance criteria for the events selected for the event categories (including within the design-basis category, selected credible events having the potential for high consequence source terms) and have the capability to establish controlled leakage and release of delayed accident source term radionuclides.

This criterion is same as Option 2 that credible very low probability, high consequence, source term events, such as, potentially, the failure of the cross-connect duct/vessel, be included in the design-basis event category. For modular HTGRs, this option would still likely allow a VLPC. However, it would further prescriptively require that the VLPC have the capability to establish controlled leakage and release of delayed accident source term radionuclides following the depressurization event. This VLPC design has been referred to as a “hybrid containment” because it would allow the initial RCS depressurization to vent directly to the environs for loss of reactor coolant pressure boundary events, but would require that the VLPC have the capability to establish a controlled, low leakage, thereafter. This option would limit the volume of air in-leakage available for core oxidation and would limit the volume of air out-leakage available for radionuclide transport to the environs of the delayed radiological source term. Accordingly, this option is also responsive to the July 30, 1993 SRM for SECY-93-092.

Currently, not all HTGR designs require that the VLPC have the capability the limit the in-leakage rate and out-leakage rate from the VLPC to a controlled limited value after a severe depressurization event. Accordingly, for such plants, this option would likely involve some VLPC design changes. For such plants, this option would also likely require structural changes to the VLPC design in order to meet structural stress (i.e., ASME) limits and upgrades to the vent system in order to assure a reliable vent path reclosure capability. This would add to the design and construction costs of the VLPC.

Because modular HTGRs, are expected to involve a relatively low release of radionuclides into the VLPC during normal operation and frequency-based design-basis events, public confidence could be enhanced. Including the capability for controlled leakage and release of the delayed accident source term radionuclides would likely further increase public confidence relative to Options 1 or 2.

Option 4: The containment must adequately reduce radionuclide releases to the environs to meet the onsite and offsite radionuclide dose acceptance criteria for the events selected for the event categories (including within the design-basis category, selected credible events having the potential for high consequence source terms) by being essentially leak tight against the release of prompt and delayed accident source term radionuclides.

This option would prescriptively require that modular HTGRs have a conventional LWR containment design rather than a VLPC. It would prevent the release to the environs of both the initial and delayed source term. It would also effectively limit the volume of air that would be available for core graphite oxidation as a result of a bounding air ingress event. However, a conventional containment would have a negative impact on modular HTGR safety by reducing the effectiveness of the passive design approach to decay heat removal and by retaining the motive force for radionuclide transport for core heatup events. This option is not consistent with the position taken in the Commission’s July 30, 1993, SRM, nor with the Commission’s advanced reactor policy, which states that regulatory guidance must be sufficiently general to avoid placing unnecessary constraints on the development of new design concepts.

This option is inconsistent with the Commission white paper on risk-informed and performance-based regulation and the performance-based approach to containment functional performance criteria proposed by modular HTGR designers.

For modular HTGRs, this option would add substantially to the cost which is not considered commensurate with the safety benefits. HTGR designers state that this option would make plant designs uneconomical. This option is also inconsistent with the Commission’s prior decision documented in the SRM for SECY-93-0092, but could result in higher public confidence than Options 1, 2, or 3.